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# PERFORMANCE STUDY OF A 3-TON RESIDENTIAL CO<sub>2</sub> A/C SYSTEM WITH A VARIABLE FLOW RATE CO<sub>2</sub> COMPRESSOR

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## ABSTRACT

A 3-ton CO<sub>2</sub> AC system is examined with a fixed displacement compressor. Performance of this system is then compared using a WhiteMoss variable flow rate CO<sub>2</sub> compressor. Analysis is carried out using simulation software. The study shows significant promise in coefficient of performance improvement plus the ability to maintain cooling performance under environmental conditions beyond the fixed displacement design point. This attractive extended performance range and improved efficiency can be expected to reduce the number of manufactured system models necessary to cover a given spectrum of applications. Manufacturing savings through economy of scale should reduce cost and improve market share.

## 1. INTRODUCTION

The system simulated is of a nominal 3-ton (9.60 kw) split cycle CO<sub>2</sub> A/C system using micro channel heat exchangers and a liquid-to-suction line heat exchanger module—as tested by the University of Illinois (Beaver *et al.*, 1999) with a,

- fixed displacement axial compressor with reed valves,
- compressor displacement = 41.4 cc,
- volumetric efficiency = 72.5%,
- mechanical efficiency = 90%,
- RPM = 1275,
- initial inlet pressure = 4.302 Mpa,
- initial outlet pressure = 10.395 Mpa.

The MicroCO<sub>2</sub> simulation software package can be licensed through the Purdue Research Foundation (PRF) and is used to model the performance of the above fixed compressor system—assembled and tested at the University of Illinois (Beaver *et al.*, 1999) using the *IllinoisInput.txt* example input data file included with MicroCO<sub>2</sub>. The *IllinoisInput.txt* data file is itself based upon the above system but since 1999 has been refined and supplemented through the PRF MicroCO<sub>2</sub> development effort. Thus, the comparison of simulated performance, using MicroCO<sub>2</sub>, can be directly made with an established simulation profile taken from that hardware. Two basic compressors are evaluated in the 3-Ton (9.60 kw) CO<sub>2</sub> split system A/C. These are a,

- fixed displacement axial compressor with reed valves,
- WhiteMoss variable adaptation of the above fixed compressor configuration and which always maintains the original fixed compression ratio,
- The common design point is 32,781 btu/hr at 110 °F outside air temperature (9.60 kw at 43.3 °C) with an outside relative humidity of 30%,
- Inside air temperature is constant at 80 °F (26.7 °C).

Typically, A/C systems are configured around an ambient design point meeting the needs of the user. This design point represents a worse-case scenario which results in a system with significant over capacity for average use. Cooling is then modulated by cycling the system ON/OFF to achieve temperature control. Ideally, one would design a system with variable capacity and with the ability to match precisely the current ambient needs. Industry has been moving toward this through variable fan speeds and variable or dual speed compressors. The question is, how much system enhancement might be expected with CO<sub>2</sub> utilizing a fully variable flow rate compressor?

## 2. COOLING CAPACITY

Figure 1 plots the MicroCO<sub>2</sub> simulation cooling capacity of the system against ambient temperature. The system is designed for a worse-case scenario—in this instance, a capacity of 9.60 kw at 43.3 °C. As expected, the system is over designed for any ambient conditions below 43.3 °C. The result is unnecessary inefficiencies. Indeed, to perform at all, the system must be cycled ON/OFF to prevent over cooling. This observation, well known, has led to many new designs with dual or variable speed compressors to achieve more than one ideal design point. By employing a fully variable flow rate compressor, one is able to continuously deliver an ideal compressor flow rate. Figure 1 also shows results for such a variable compressor adapting to a constant design cooling capacity. For a proper comparison, the compressor variability module has been adapted to the original fixed displacement compressor with reed valves and its 72.5% volumetric efficiency, while the WhiteMoss variable compressor design uses a port plate valve system with an improved volumetric efficiency of nearer 85% which would further reduce the required displacement of the compressor.

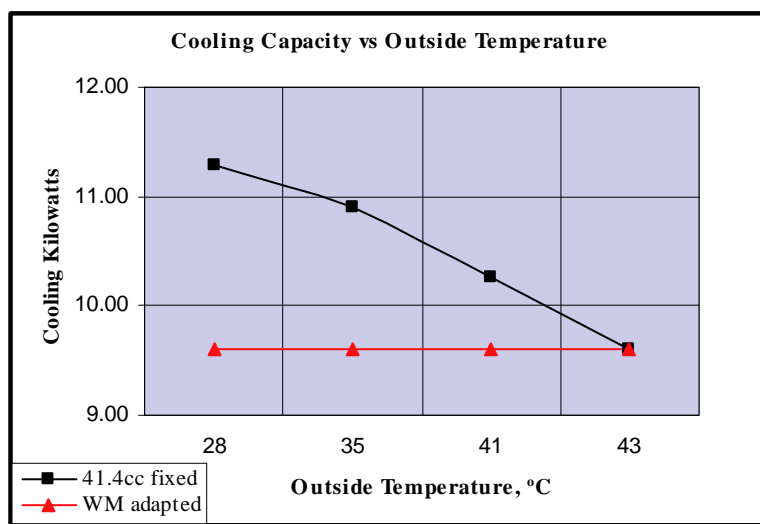


Figure 1—Cooling Capacity

## 3. VARIABLE FLOW RATES

Variable flow rate as a function of temperature is shown in Figure 2 as a change in displacement with ambient temperature as the variable compressor resizes to maintain the given cooling rate. It should be kept in mind that as ambient temperature decreases, the cooling demand load will also be reduced. Here, however, the demand load has been fixed for comparison purposes. This requires a reduction in displacement of 27%. Using the port plate compressor shifts the curve displacement downward another 11% (not shown).

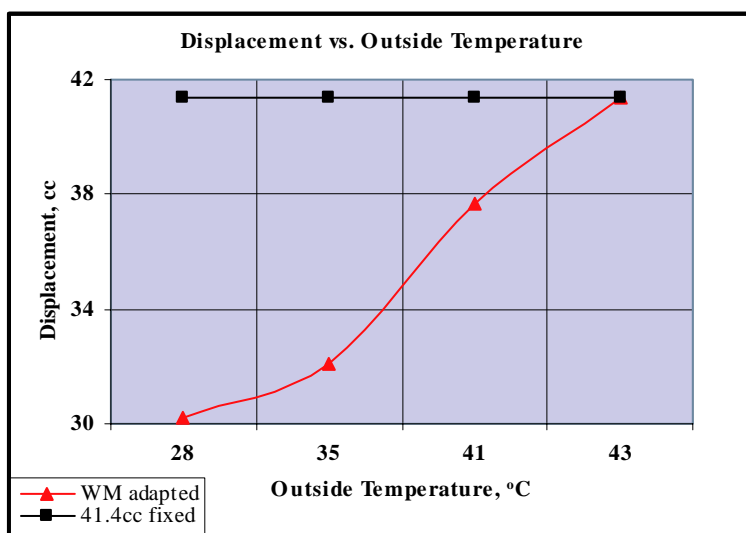


Figure 2—Displacement

#### 4. COMPRESSOR POWER

Figure 3 shows the compressor power in kilowatts used by the two compressors for this fixed load example. Keep in mind that the variable compressor would be running continuously while the fixed compressor system would be cycling to meet the fixed cooling capacity for the reduced cooling load under the falling ambient temperatures; consequently, the full kilowatt gap shown is not all salvaged. A more accurate indication of efficiency savings would be any improvement shown in coefficient of performance (COP) with variability.

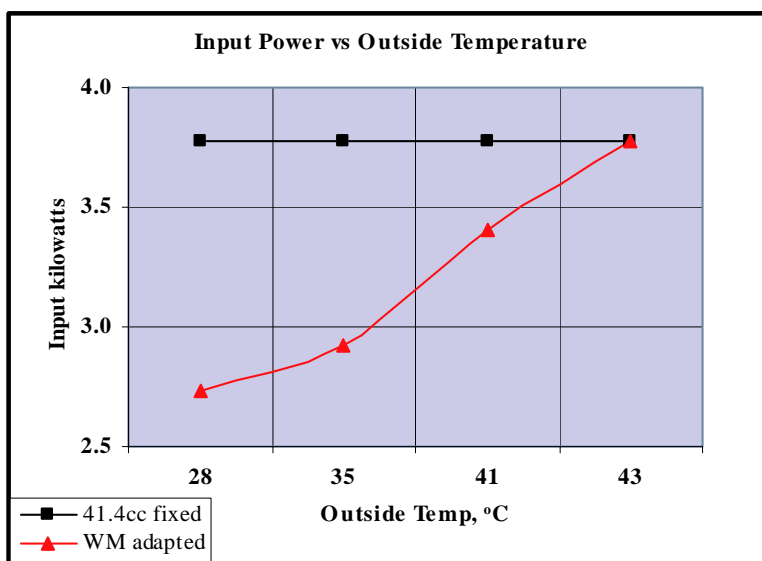


Figure 3—Kilowatts Used

## 5. CHANGE IN COP WITH VARIABILITY

Figure 4 plots system COP against outside temperature. This is a more realistic indicator of the improved performance one can expect since COP is a measure of system efficiency while the system is running.

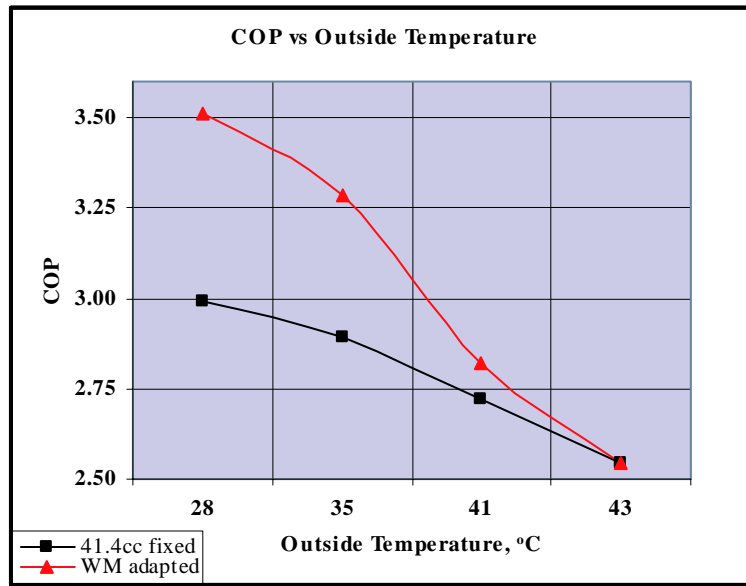


Figure 4—COP Performance

Thus, if the COP is improved then the system can be expected to be more efficient compared to a cycling fixed displacement compressor system with a lesser COP. Note that under all conditions the variable compressor is the more efficient—reaching an improvement of 17% at 27.8 °C.

## 6. CONCLUSIONS

Clearly, the advantages of a variable compressor are significant. In the above analysis, the design point was a constant cooling capacity under all ambient temperatures. However, cooling requirements can be expected to *decrease* with lower ambient temperatures—allowing the variable compressor to further reduce flow rates and improve COP efficiencies. In addition, there is always the case of an unusual ambient state requiring a temporary *increase* in cooling capacity beyond the original fixed design point. This suggests a further advantage. By using a larger maximum displacement variable flow rate compressor, variability permits the compressor to *resize upward* and supply added emergency capacity. Variability allows a single maximum capacity system to successfully match a range of cooling load requirements which might otherwise require a manufacturer to span with several fixed compressor units.

### 6.1 MicroCO2 ISSUES

MicroCO2 is an effort to achieve simulation with a completely detailed CO<sub>2</sub> system configuration. For example, there are in the input data file *IllinoisInput.txt*,

- 19            system level variable values
- 46            evaporator module variable values
- 44            gas cooler module variable values
- 8            compressor module, configuration variables

5	compressor module, overall efficiency correlation coefficients
5	compressor module, mass flow rate map coefficients
4	compressor module, volumetric efficiency correlation coefficients
1	expander module, isentropic expander efficiency
6	expander module, isentropic efficiency correlation coefficients
26	liquid-to-suction line heat exchanger module variable values

It is important to realize that the MicroCO<sub>2</sub> simulation software is an *over determined initial value system*. This means that too many variables are input to casually expect a trouble free and stable mathematical convergence in all cases. In such instances, one must initialize with input data very close to actual physical system data—you must know the answer before you start!). However, there is a way. The process is to make the best possible estimates of the correct input values and through the results of multiple trials, continue to refine the input values until stable convergence occurs. This requires care in the use of such simulation software and a good understanding of the expected engineering results—otherwise there may be no convergence at all; or, the simulation may converge to one of many alternate eigenvalues. These alternate nodes of convergence may be mathematically correct but represent solutions of no physical relevance. With this *caveat*, MicroCO<sub>2</sub> can be a very powerful tool in the study and optimization of complex CO<sub>2</sub> systems.

## 6.2 Comments

The MicroCO<sub>2</sub> analysis compared fixed compressor CO<sub>2</sub> systems with identical system components—only variability was added to the given compressor. No additional optimizations were considered such as,

- variable fan flow rates and consequent energy savings,
- reduced cooling loads with reduced ambient temperatures,
- compressor modifications to enhance variability performance,
- adding variable compression ratio to improve performance.

In this simulation the compressor input compression ratio remained constant throughout with only the flow rate being changed. The WhiteMoss compressor, however, does allow for flow rate changes with an independently adjustable compression ratio as well as the fixed compression ratio used in these simulations. A further addition of independently variable compression ratio effects would be a next step to the current MicroCO<sub>2</sub> study.

## REFERENCES

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## ACKNOWLEDGEMENT

### MicroCO2

The Purdue Research Foundation provides the computer software program *MicroCO2* and licenses its non-exclusive use to the authorized end-user.

This work is a computer software program called “MicroCO2” (derived from an earlier program in Fortran, “ACCO2”), used to design carbon dioxide based air conditioning systems or to predict the performance of existing systems. It is comprised of source code developed and written by researchers at Purdue University, and makes use of libraries written by third parties as covered under separate agreements or as noted below. The program may be run on a personal computer running either Mac OS or Microsoft Windows operating systems. In its executable form, no other utilities are needed to run MicroCO2.

To compile the source code, one must have available a copy of the f2c library (f2c is a Fortran to C translation utility, available for download from [netlib.org](http://netlib.org)). The program also requires a copy of a carbon dioxide material property library developed by Span and Wagner at Ruhr University of Bochum in Germany (available from the Institute of Thermodynamics, Ruhr University of Bochum, Germany; for more information please contact Prof. Dr.-Ing. W. Wagner, phone: +49 234 32-23033, Fax: +49.234.32-14163, email: [Wagner@thermo.ruhr-uni-bochum.de](mailto:Wagner@thermo.ruhr-uni-bochum.de)). In addition, the Software includes a matrix library developed by Somnath Kundu (matrix class library by Kundu, C++), which is being transferred under the terms of the GNU General Public License.